TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 168

EXPERIMENTS WITH FABRICS FOR COVERING AIRPLANE WINGS, TO DETERMINE EFFECT OF METHOD OF INSTALLATION.

By A. Pröll.

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EXPERIMENTS WITH FABRICS FOR COVERING AIRPLANE WINGS, TO DETERMINE EFFECT OF METHOD OF INSTALLATION.*

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The following notes relate primarily to the effect of changes in the loading and in the disposition of the supporting framework (regarded as rigid) on the covering fabric.

The magnitude of the air forces to be taken into account and the corresponding factors of safety to be expected will be discussed later.

In the same way, the important inter-relations between the loading of the fabric and the deformation of the framework will be reserved for further research. The strength of a fabric is of prime importance in deciding upon a wing covering. This does not depend on the properties of the fabric alone, but also on the supporting framework. Another factor, almost as important, is the deformation of the fabric during flight, which, under certain circumstances (by alteration of the shape of the wing section), may have a determining effect on the aerodynamic properties of the wing.

Lastly, secondary stresses are produced by the mutual reactions between fabric and frame, which must be allowed for in calculations and turned to account in the designing of the ribs and spars.

* From Technische Berichte, Vol.III, No.6, (1918), pp. 234-246.

Since the tensions in a loaded wing covering can not be observed directly, an effort must be made to determine them by means of distortion, through comparison with the tensions given by the N.C. (normal coefficients) for similar distortions.

For a uniform wing loading, the tensions and distortions were determined in a subsequent investigation. The calculations take a somewhat different form for the fabric on a wing with initial double curvature. The ribs determine the curvature in the direction 2, but, in the other direction 1, at right angles, the radius of curvature is originally infinite. On subjecting the fabric to initial tensions S_{1_c}, S_{2_0}, a surface with double curvature is formed spontaneously, since the equation is

$$p = 0 = \frac{S_{1_0}}{\rho_{1_0}} + \frac{S_{2_0}}{\rho_{2_0}} \tag{1}$$

S_{1_0}, S_{2_c}, ρ_{2_0} are positive, so that ρ_c must be negative, that is, with the convex surface upward in the position for sand loading. The radii ρ_{1_c}, ρ_{2_0} can be easily calculated from the observed transverse cambers based on parabolic curves.

The original cambers f_{1_0}, f_{2_0} are measured from the outer edge of the ribs and from the chord (Figs. 1-3).

The fabric is held fast at the ribs, where it has a camber f and usually a greater initial elongation than half-way between the ribs, where the camber f_{2_0} in the unloaded state is smaller, that is, where the radius of curvature is greater than at the ribs. The camber is increased f' by loading.

The calculation is based on a strip of fabric half-way between the ribs, for which the initial elongations ϵ_{1_0}, ϵ_{2_0} are generally unknown, unless it has been possible to measure them when putting on the fabric. Further, if the N.C. of the fabric are known, then S_{1_c}, S_{2_c} can be calculated as follows:

Two curves F_1, F_2 (Fig. 4) connect all points for which, in the N.C., the following relation holds:

$$\frac{S_{1_0}}{S_{2_0}} = - \frac{\rho_{1_0}}{\rho_{2_0}} \qquad (2)$$

Dotted lines are drawn parallel to the axis of abscissas at the heights ϵ_{1_0} and ϵ_{2_0}, cutting the curves F_1, F_2 at the points A' and A". These points give the correct condition of the initially stressed fabric. They must lie on the same ordinate, by which the accuracy of the calculations and of the N.C. may be checked.

If the N.C. are given by equations, then we have to solve:

$$\begin{aligned} \epsilon_{1_0} &= \beta_1 S_{1_0} - c_1 S_{2_0} \\ \epsilon_{2_0} &= \beta_2 S_{2_c} - c_2 S_{1_0} \end{aligned} \qquad (3)$$

In agreement with the graphic solution, there is one more equation than there are variables, by means of which the computation may be checked or corrected. It is presupposed, for this computation, that the initial elongations ϵ_{1_0}, ϵ_{2_0} have been measured in putting on the fabric.

This, however, is not usually the case. Then ϵ_{1_0} and ϵ_{2_0}

are unknown, and their relation is given by

$$\frac{\epsilon_{1_0}}{\epsilon_{2_0}} = \frac{\beta_1 + c_1\left(\frac{\rho_{2_0}}{\rho_{1_0}}\right)}{-\beta_2\left(\frac{\rho_{2_0}}{\rho_{1_0}} + c_1\right)} \tag{4}$$

In order to calculate them, a loading test must be carried out. With a load of p (kg/m²), the tensions S_1 and S_2, the total elongations ϵ_1 and ϵ_2, and the additional camber f' in the center of the area under consideration are obtained. ρ_1 and ρ_2 are the radii of curvature calculated from the camber.

Then

$$\frac{S_1}{\rho_1} + \frac{S_2}{\rho_2} = p \tag{5}$$

$$\left.\begin{aligned} \epsilon_1 &= \beta_1 S_1 - c_1 S_2 \\ \epsilon_2 &= \beta_2 S_2 - c_2 S_1 \end{aligned}\right\} \tag{6}$$

However, only the differences are measured:

$$\epsilon_1 - \epsilon_{1_0} = \frac{8}{3}\,\frac{(f_{1_0} + f')^2 - f_{1_0}^2}{l_1^2} \tag{7}$$

$$\epsilon_2 - \epsilon_{2_0} = \frac{8}{3}\,\frac{(f_{1_0} + f')^2 - f_{1_0}^2}{l_1^2} \tag{8}$$

For calculating the unknown quantities ϵ_{1_0}, ϵ_{2_0}, ϵ_1, ϵ_2, S_1 and S_2, six equations are now available.

<u>Example</u>: Let the N.C. be expressed by

$$\left.\begin{aligned} 10^6\ \epsilon_{1_0} &= 120\ S_{1_0} - 30\ S_{2_0} \\ 10^6\ \epsilon_{2_0} &= 62\ S_{2_0} - 51\ S_{1_0} \end{aligned}\right\} \text{ for } p = 0$$

With l_1 = 0.32 m (1.05 ft) rib-spacing, the measurement of the camber on the unloaded fabric gives

$$f_{1_0} = -0.5 \text{ cm } (.0164 \text{ ft}); \quad \rho_{1_0} = -2.8 \text{ m } (-9.186 \text{ ft});$$

$$\rho_{2_0} = 4.0 \text{ m } (13.123 \text{ ft}),$$

corresponding to the circular form of wing curvature with ρ_2 = 4 m (13.123 ft).

Whence

$$-\frac{S_{1_0}}{2.8} + \frac{S_{2_0}}{4.0} = 0$$

which gives

$$\frac{S_{2_0}}{S_{1_0}} = 1.43; \qquad \frac{\epsilon_{1_0}}{\epsilon_{2_0}} = \frac{77}{34} = 2.08$$

Let the additional camber, measured for the load p = 150 kg/m² (8.4 lb/in) be by measurement f' = 1.75 cm (.0574 ft) so that $f_{1_0} + f'$ = 1.25 cm (.041 ft) $f_2 + f'$ = 7.75 cm (.254 ft) on a length of 153 cm (5.02 ft) from which we calculate the radius of curvature, ρ_1 = 0.67 m (2.198 ft) and ρ_2 = 3.78 m (12.401 ft).

Further, by equation (7), we have

$$\epsilon_1 - \epsilon_{1_0} = 0.00346, \quad \epsilon_2 - \epsilon_{2_0} = 0.00260$$

and, by equation (5),

$$\frac{S_1}{0.67} + \frac{S_2}{3.78} = 150$$

so that $S_2 = 570 - 5.62\, S_1$

Lastly, from the N.C. we have the relations:

$$10^6 \ \epsilon_1 = 120 \ S_1 + 169 \ S_1 - 17100 = 289 \ S_1 - 17100$$

$$10^6 \ \epsilon_2 = -51 \ S_1 - 348 \ S_1 + 35300 = -399 \ S_1 - 35300$$

from which we have

$$\frac{\epsilon_{1_0}}{\epsilon_{2_0}} = \frac{289 \ S_1 - 20560}{-399 \ S_1 + 32700} = 2.08$$

This gives

$$S_1 \sim 80 \text{ kg/m } (4.48 \text{ lb/in}), \ S_2 \sim 120 \text{ kg/m } (6.72 \text{ lb/in})$$

and $\epsilon_1 \sim \dfrac{5400}{10^6}, \ \epsilon_2 \sim \dfrac{3420}{10^6}$

while the original condition of the fabric is designated by

$$\epsilon_{1_c} \sim \frac{1940}{10^6} \qquad \epsilon_{2_0} \sim \frac{820}{10^6}$$

and

$$S_{1_c} = 25 \text{ kg/m } (1.4 \text{ lb/in}), \qquad S_{2_0} = 35 \text{ kg/m } (1.96 \text{ lb/in}).$$

In working out this and similar examples, small variations in equation (6) have great influence on the final result. The calculation respecting the elongations ϵ is, therefore, not very accurate. On the other hand, the examples show that the tensions S_1 and S_2 are little affected by inaccuracies in the calculation of the elongations and, besides, never differ much. Since the entire calculation is only an approximation, it can be greatly simplified, by finding the approximate tensions from the C-curves, the calculation and application of which have been previously demonstrated.*

* A. Pröll. "Zur Frage der Festigkeit von Tragflachenbespannungen," Zeitschrift fur Motorluftschiffahrt und Flugtechnik, 1915, Nos. 3 & 6.

Between the tensions S_1, S_2 and the corresponding elongations ϵ_1, ϵ_2 in the two principal directions, with a uniform load p kg/m², we have the relation

$$S_1^2\ \epsilon_1 = \frac{p^2 l_1^2}{24} \left(1 - \frac{S_2}{p\,\rho_2}\right)^2$$

This equation gives in the S_1, ϵ system of coordinates of the N.C., a group of curves with p as parameter, which can be drawn on the diagram of the known N.C. of the fabric (Fig. 5). For a given load p, the first trial point on the fabric diagram, with respect to the elongation ϵ_1, must lie on the corresponding C-curve and it only remains to determine whether the elongations calculated from the measured transverse curvatures of the loaded fabric agree with this. If, however, the tensions in the fabric are calculated in the manner described above, they always lie in the neighborhood of the fairly well defined peak of the C-curves, where S_1 and S_2 differ but little. The latter is a general property of stretched membranes of isotropic material, where the tension may be considered the same in every direction. Here it holds good for only the two main directions and there only approximately.

In most cases, the tension can be determined with sufficient accuracy as follows:

A point near the peak of the C-curve is found, giving almost equal values for S_1 and S_2, lying, therefore, at the intersection of the C-curve with the γ_1-curve connecting all points for which $S_1 = S_2$ (See Technische Berichte, Vol.III, No.2, p.64), and the tension and elongation are read off.

If the example given above is gone through in this way, then the C-curves for $p = 150$, 100 and 50 kg/m, $l_1 = 0.32$ (1.05 ft) and $\rho_2 = 4.0$ m (13.123 ft) are shown in Fig. 5. The point A, where S_1 and S_2 are equal, leads to $S_1 \sim S_2 = 102$. It must be noted at this point, that the elongations are in accord. At the point A we would have $\epsilon_1 \sim 0.007$ and $\epsilon_2 \sim 0.001$, which is inaccurate. Hence, we shift the trial point along the C-curve, until the elongation acquires a usable value. Thus, a point B is found, with $S_1 \sim 105$, $S_2 \sim 115$, $\epsilon_1 \sim 0.0058$ and $\epsilon_2 \sim 0.003$.

Better agreement with the calculation was really not to be expected and is unnecessary, considering the variable characteristics of the fabric. If the initial tension is to be obtained, it is necessary, however, to resort to calculation.

Effect of Different Arrangements of the Supporting Framework.

This was tested with the aid of a wing frame of 1.53 m (5.020 ft) chord (Figs. 6 & 7) consisting of two spars and four ribs, capable of different settings on the spars. The ribs could be replaced by others of different camber. The wing was covered only on the lower side, the fabric being, as usual, stretched and doped and, if necessary, painted, and then loaded. The deflection of the fabric was measured at various points (Note.- For this purpose, fine threads were used, attached at the points of measurement and weighted. Knots were made in them, whose varying heights were measured from a fixed horizontal base) and marked on the diagram, so that deflection curves were obtained for both principal directions 1 and 2 (at right angles and parallel to the ribs) for each load and for the fabric not under load. From the deflection thus obtained, the representative point on the fabric was ascertained and then the tension and elongation by means of the C-curves.

In order to obtain loads varying, as nearly as possible, the same as during flight, the following sequence and duration of the loadings were maintained approximately in the majority of the experiments.

No.	Load		Duration
	kg/m^2	lb/ft^2	
1	55	11.265	15 minutes
2	0	0.000	60 "
3	165	33.795	15 "
4	165	33.795	15 "
5	0	0.000	12 to 15 hours
6	55	11.265	15 minutes
7	110	22.530	15 "
8	0	0.000	5 - 6 hours
9	110	22.530	15 minutes
10	275-350	$\begin{Bmatrix}53.325\\71.686\end{Bmatrix}$	15 "
11	0	0.000	27 - 36 hours
12	275-350	$\begin{Bmatrix}53.325\\71.686\end{Bmatrix}$	24 hours

In general, the N.C. determined by multi-cross experiments was taken as the basis of the calculation, on the assumption that a multi-cross test with rapid changes of load, corresponds best to normal loads in an airplane.

The ribs of the wing frame were made from 12 mm (.472 in) boards, bent to an arc of ρ_2 = 8 or 4 m (26.247 or 13.123 ft) radius. Their spacing on the spars could be set at 23 (9.06), 28 (11.02), 32 (12.6), 40 (15.75) and 50 cm (19.68 in). The spars were solid and were placed 90 cm (35.43 in) apart. They rested on supports 2 m (6.56 ft) apart and deflected only 4 to 5 cm (1.57 to 1.97 in) in the middle with full sand loading - 300 kg/m² (61.445 lb/ft²). The bending of the ribs was very small and was taken into consideration during the tests only in so far as it slightly affected the curvature of the wing. Moreover, the total deflection f, was measured each time at nine points of the measured length l. From this, with the assumption of a flat parabolic curve, the radius of curvature ρ was calculated by the formula $\rho = \frac{l^2}{8f}$ (See Figs. 6 & 7).

With ρ_2 = 8 m (26.247 ft) and l_2 = 50 cm (1.64 ft) rib-spacing, the fabric on the spars was already under $p \sim 60$ kg/m² (12.289 lb/ft²) load. The measured data were transformed accordingly.

During some of the experiments, the recording instrument was suspended from the lower side of the fabric and so balanced as to follow the motions of the surface. The instrument indicated the distortions very well in a direction parallel to the ribs.

Perpendicular to this direction, the record is of no value and therefore, owing to the large camber, the deflection must be measured directly.

Fabric B (Technische Berichte, Volume III, No. 2, p.66), a doubly doped fabric from Hauser and Spiegel at Bischweiler, was used for most of the experiments, having been already used for the N.C. experiments (Figs. 4 & 5), as well as for most of the elongation tests, since, in the first place only the effect of different dispositions of the supporting frame came into question. It was, therefore, appropriate to use, for all experiments, a fabric which satisfactorily exhibited the qualities of the doped fabric, the doping of which, however, would still allow the fabric itself to appear as carrying the load. In some of the experiments, the fabric was twice doped, then painted and varnished. These experiments showed the predominating influence of the varnishing on the behavior of the fabric. The results are all given in Tables I to V. Table I exemplifies the determination of the deflection at nine points, from which the additional camber f' at the center was calculated.

The following remarks apply to the tables:

1. The deflection was measured perpendicular to the ribs from their upper edge and the deflection in a direction parallel to the ribs was obtained each time, graphically or by a short calculation, taking into consideration the known curvature and the deflection of the ribs.

2. In one case (Table I), with repeated loading and unloading, the consecutive figures for one stage in the loading have been entered in the time sequence of the loadings.

3. The assumed average values of the deflection with repeated loading and unloading have been given, with the maximum values added in brackets.

From the known initial deflection, in each separate case, the tension, elongation and initial tension can be calculated from the deflection f' under the load p. This somewhat elaborate method was repeatedly used in checking tests. In general, however, the simplified method, using C-curves, has been followed. The results are contained in Tables VI and VII, and Figures 8 to 16.

Table II.

Fabric B, doped twice.
ρ_2 = 8.0 m (26.247 ft), l_2 = 0.4 m (1.312 ft)
Measurements of supporting surfaces.

LOAD		Point of measurement 1 mm in	2 mm in	3 mm in	4 mm in	5 mm in	Remarks
0	kg.m²	204.5	-3.7 133.2	162.0	141.2	-4.2 159.5	Initial camber
0	lb/ft²	8.051	-.146 5.244	6.378	5.559	-.165 6.279	" "
36.7	kg/m²	204.0 0.5	116.0 17.2	161.1 9.9	140.0 1.2	138.0 21.5	Camber Deflection
7.517	lb/ft²	8.031 .020	4.567 .677	6.342 .390	5.512 .047	5.433 .846	Camber Deflection
55	kg/m²	203.2 1.3	113.0 20.2	160.8 1.2	139.5 1.7	135.5 24.0	Camber Deflection
11.265	lb/ft²	8.000 .051	4.449 .795	6.331 .047	5.492 .067	5.335 .945	Camber Deflection
55	kg/m²	203.1 1.4	113.2 20.0	160.5 1.5	139.5 1.7	135.6 23.9	Camber Deflection
11.265	lb/ft²	8.000 .055	4.457 .787	6.319 .059	5.492 .067	5.339 .941	Camber Deflection
165	kg/m²	201.1 3.4	105.8 27.4	158.1 3.9	137.1 4.1	125.1 34.4	Camber Deflection
33.795	lb.ft²	7.917 .134	4.165 1.079	6.224 .154	5.398 .161	4.925 1.354	Camber Deflection
0	kg/m²	204.2 0.3	132.9 0.3	161.0 1.0	140.9 0.3	159.1 0.4	Camber Deflection
0	lb/ft²	8.039 .012	5.232 .012	6.339 .039	5.547 .012	6.224 .016	Camber Deflection
110	kg/m²				137.8 3.1	129.1 30.0	Camber Deflection
22.530	lb/ft²				5.425 .122	5.083 1.181	Camber Deflection
165	kg/m²				136.1 4.8	124.4 34.7	Camber Deflection
33.795	lb/ft²				5.358 .189	4.898 1.366	Camber Deflection

Table I (Cont.

Fabric B, doped twice.

ρ_2 = 8.0 m (26.247 ft), l_2 = 0.4 m (1.312 ft)

Measurements of supporting surfaces.

LOAD		Point of measurement 6 mm in	7 mm in	8 mm in	9 mm in	Remarks
0	kg/m²	114.2	135.1	-2.7 119.2	163.0	Initial camber
0	lb/ft²	4.500	5.319	-.106 4.693	6.417	" "
36.7	kg/m²	113.0 1.2	133.5 1.6	104.2 15.0	161.7 1.3	Camber Deflection
7.517	lb/ft²	4.449 .047	5.256 .063	4.102 .591	6.366 .051	Camber Deflection
55	kg/m²	112.7 1.5	133.2 1.9	103.0 16.2	161.0 2.0	Camber Deflection
11.265	lb/ft²	4.437 .059	5.244 .075	4.055 .638	6.339 .079	Camber Deflection
55	kg/m²	112.0 2.2	133.0 2.1	100.0 19.2	161.1 1.9	Camber Deflection
11.265	lb/ft²	4.409 .0087	5.236 .083	3.937 .756	6.342 .075	Camber Deflection
165	kg/m²	109.5 4.7	130.6 4.5	93.7 25.5	158.9 4.1	Camber Deflection
33.795	lb/ft²	4.311 .185	5.142 .177	3.689 1.008	6.256 .161	Camber Deflection
0	kg/m²	113.1 1.1	134.7 0.4	119.7 -0.5	162.9 0.1	Camber Deflection
0	lb/ft²	4.453 .043	5.303 .016	4.713 -.020	6.413 .004	Camber Deflection
110	kg/m²	110.3 2.8				Camber Deflection
22.530	lb/ft²	4.342 .110				Camber Deflection
165	kg/m²	109.5 3.6				Camber Deflection
33.795	lb/ft²	4.311 .142				Camber Deflection

The following conclusions can be drawn from these results:

1. The tension increases approximately in direct proportion to the rib-spacing, the load remaining the same, in accordance with the general equations:

$$\begin{aligned} S_1 &= A_1 + B_1\, l_1 \\ S_2 &= A_2 + B_2\, l_2 \end{aligned} \qquad (1)$$

For the twice-doped fabric B here tested, with $p = 100\ \mathrm{kg/m^2}$ $(20.482\ \mathrm{lb/ft^2})$, we have

$$\rho_2 = 8\ \mathrm{m}\ (26.247\ \mathrm{ft}) \begin{cases} S_1 = 180\, l_1 + 23 \\ S_2 = 210\, l_1 + 12 \end{cases}$$

$$\rho_2 = 4\ \mathrm{m}\ (13.123\ \mathrm{ft}) \begin{cases} S_1 = 138\, l_1 + 30 \\ S_2 = 186\, l_1 + 27 \end{cases}$$

2. With equal rib-spacing l, the linear tensions increase likewise, approximately in direct proportion to the load:

$$\left.\begin{aligned} S_1 &= S_{1_c} + \zeta_1\, p \\ S_2 &= S_{2_c} + \zeta_2\, p \end{aligned}\right\} \qquad (2)$$

in the present case, with $l_1 = 0.5\ \mathrm{m}\ (1.64\ \mathrm{ft})$ and

$$\rho_2 = 8\ \mathrm{m}\ (26.247\ \mathrm{ft}) \begin{cases} S_1 = 16 + 0.9\, p \\ S_2 = 40 + 0.74\, p \end{cases}$$

$$\rho_2 = 4\ \mathrm{m}\ (13.123\ \mathrm{ft}) \begin{cases} S_1 = 15 + 0.82\, p \\ S_2 = 47 + 0.69\, p \end{cases}$$

Table II.

Fabric B, doped twice.
ρ_2 = 4.0 m (13.123 ft).

l_1	m	0.23	0.32	0.40	0.50
	ft	.755	1.050	1.312	1.640
Deflection		$f_{1_0} + f'$ mm in.			
p = 0	kg/m²	-2.40	-6.1	-8.0	-10.2
0	lb/ft²	-.094	-.240	-.315	-.402
50	kg/m²		10.0		7.9 (10.6)
10.241	lb/ft²		.394		.311 (.417)
55	kg/m²	4.25 (6.25)			
11,265	lb/ft²	1.673 (.246)			
110	kg/m²	7.35 (8.80)		17.4 (20.2)	17.7 (19.7)
22.530	lb/ft²	.289 (.346)		.685 (.795)	.697 (.776
150	kg/m²		17.5		24.6 (26.3)
30.723	lb/ft²		.689		.969 (1.035)
165	kg/m²	9.15 (9.35)		19.8 (21.5)	
33.795	lb/ft²	.360 (.368)		.780 (.846)	
250	kg/m²		23.0		
51.204	lb/ft²		.906		
265	kg/m²				31.2
54.277	lb/ft²				1.228
275	kg/m²	10.52		27.4	
56.325	lb/ft²	.414		1.079	

Table II. (Cont.)

Fabric B, doped twice.
l_2 = 4.0 m (13.123 ft).

l_1	m	0.23	0.32	0.40	0.50
	ft	.755	1.050	1.312	1.640
Deflection		$f_{s_0} + f'$ mm in.			
p = 0	kg/m²	71.3	67.6	65.7	63.5
0	lb/ft²	2.807	2.661	2.587	2.500
50	kg/m²		83.7		
10.241	lb/ft²		3.295		
55	kg/m²	77.9 (79.9)		79.3 (85.4)	81.6 (84.3)
11.265	lb/ft²	3.067 (3.146)		3.122 (3.362)	3.213 (3.319)
110	kg/m²	81.0 (82.5)		91.1 (93.8)	91.4 (93.4)
22.530	lb/ft²	3.193 (3.248)		3.587 (3.693)	3.598 (3.677)
150	kg/m²		91.2		
30.723	lb/ft²		3.591		
165	kg/m²	82.9 (83.1)		93.5 (96.2)	98.3 (99.9)
33.795	lb/ft²	3.264 (3.272)		3.681 (3.787)	3.870 (3.933)
250	kg/m²		96.7	101.1	
51.204	lb/ft²		3.807	3.980	
275	kg/m²	84.2			104.9
56.325	lb.ft²	3.315			4.130

Table II (Cont.)

Fabric B, doped twice.
$\rho_2 = 4.0$ m (13.123 ft)

l_1	m	0.23	0.32	0.40	0.50
	ft	.755	1.050	1.312	1.640
Deflection		$\frac{\varphi_x - \varphi}{\varphi}$ 100*) mm in.			
p = 0	kg/m^2	-3.24	-8.30	-10.8	-13.8
0	lb/ft^2	-.128	-.327	-.425	-.543
50	kg/m^2		13.6		
10.241	lb/ft^2		.535		
55	kg/m^2	5.78 (8.5)		10.2 (15.9)	10.8 (14.3)
11.265	lb/ft^2	.228 (.335)		.402 (.626)	.425 (.563)
110	kg/m^2	9.95 (12.0)		23.6	23.8 (26.7)
22.530	lb/ft^2	.392 (.472)		.929	.937 (1.051)
150	kg/m^2		23.7		
30.723	lb/ft^2		.933		
165	kg/m^2	12.5 12.7		27.0 (29.0)	33.1 (35.3)
33.795	lb/ft^2	.492 (.500)		1.063 (1.142)	1.303 (1.390)
250	kg/m^2		31.0		
51.204	lb/ft^2		1.220		
265	kg/m^2	14.3			41.8
54.277	lb/ft^2	.563			1.646

*) Variation of camber ratio.

Table III.

Fabric B, doped twice.
ρ_2 = 8.0 m (26.247 ft)

l_1				
	m	0.32	0.40	0.50
	ft	1.050	1.312	1.640
Deflection		$f_{1_0} + f'$ mm in.		
p = 0	kg/m²	~ -3.4	-4.2	-5.1
0	lb/ft²	-.134	-.165	-.201
36.7	kg/m²		16.1	
7.517	lb/ft²		.634	
55	kg/m²		17.8 (18.2)	
11.265	lb/ft²		.701 .717	
110	kg/m²		18.8 (19.7)	
22.530	lb/ft²		.740 (.776)	
150	kg/m²	19.0		35.5 (41.1)
30.723	lb/ft²	.748		1.398 (1.618)
165	kg/m²		25.0 (26.0)	
33.795	lb/ft²		.984 (1.024)	
250	kg/m²			44.6 (44.9)
51.204	lb/ft²			1.756 (1.768)
300	kg/m²	21.0	25.9 (27.0)	
61.445	lb/ft²	.827	1.020 (1.063)	
350	kg/m²			46.6
71.686	lb/ft²			1.835

Table III (Cont.)

Fabric B, doped twice.
$\rho_2 = 8.0$ m (26.247 ft).

l_r			
m	0.32	0.40	0.50
ft	1.050	1.312	1.640
Deflection	$f_{2c} + f'$ mm in.		
p = 0 kg/m² 0 lb/ft²	31.3 1.232	30.5 1.200	39.8 1.567
36.7 kg/m² 7.517 lb/ft²		50.8 2.000	
55 kg/m² 11.265 lb/ft²		52.5 (52.9) 2.067 (2.083)	
110 kg/m² 22.530 lb/ft²		53.5 (54.4) 2.106 (2.142)	
150 kg/m² 30.723 lb/ft²	53.7 2.114		70.2 (75.8) 2.764 (2.984)
165 kg/m² 33.795 lb/ft²		59.7 (60.7) 2.350 (2.390)	
250 kg/m² 51.204 lb/ft²			79.3 (79.6) 3.122 (3.134)
300 kg/m² 61.445 lb/ft²	55.7 2.193	60.6 (61.7) 2.386 (2.429)	
350 kg/m² 71.686 lb/ft²			81.3 3.200

Table III (Cont.)

Fabric B, doped twice.
ρ_2 = 8.0 m (26.247 ft)

l_1	0.32	0.40	0.50
	1.050	1.312	1.640
Deflection		$\frac{\varphi_x - \varphi}{\varphi}\,100$ mm in.	
p = 0 kg/m² 0 lb/ft²	-9.8 -.386	12.1 .476	-14.7 -.579
36.7 kg/m² 7.517 lb/ft²		46.4 1.827	
55 kg/m² 11.265 lb/ft²		51.3 (52.6) 2.030 (2.071)	
110 kg/m² 22.530 lb/ft²		54.4 (57.0) 2.142 (2.244)	
150 kg/m² 30.723 lb/ft²	54.8 2.157		102.2 (113.6) 4.024 (4.670)
165 kg/m² 33.795 lb/ft²		72.5 (75.1) 2.854 (2.957	
250 kg/m² 51.204 lb/ft²			128.3 (129.1) 5.051 (5.083)
300 kg/m² 61.445 lb/ft²	60.6 2.386	74.8 (77.8) 2.945 (3.063)	
350 kg/m² 71.686 lb/ft²			134.5 5.295

3. Both pairs of formulas can be combined into

$$\left.\begin{aligned} S_1 &= \alpha_1 + \beta_1 p + \gamma_1 l_1 + \delta_1 p\, l_1 \\ S_2 &= \alpha_2 + \beta_2 p + \gamma_2 l_1 + \delta_2 p\, l_1 \end{aligned}\right\} \quad (3)$$

in this present case

for

$$\rho_2 = 8 \text{ m } (26.247 \text{ ft}) \begin{cases} S_1 = 6 + 0.14\, p + 24 l_1 + 1.5\, p l_1 \\ S_2 = -6.5 + 0.19\, p + 95 l_1 + 1.1\, p l_1 \end{cases}$$

for

$$\rho_2 \quad 4 \text{ m } (13.123 \text{ ft}) \begin{cases} S_1 = 6 + 0.23\, p + 17 l_1 + 1.18\, p l_1 \\ S_2 = -6.5 + 0.30\, p + 109 l_1 + 0.74\, p l_1 \end{cases}$$

If, then, the approximation $S_1 \sim S_2 = S$ is taken (for large radii of curvature), we get a good working rule:

$$S = \alpha + \beta\, p + \gamma l_1 + \delta p l_1 \qquad (4)^*$$

here, on an average

for $\rho_2 = 8$ m (26.247 ft): $S = 0.165\, p + 60\, l_1 + 1.3\, p\, l_1$

and for $\rho_2 = 4$ m (13.123 ft): $S = 0.27\, p + 63\, l_1 + 0.96\, p l_1$

4. With a greater curvature, S_1 is smaller under conditions otherwise the same and S_2 is larger than with less curvature. The almost coincident and nearly straight curves of S_1 and S_2 for large values of ρ_2 (Figs. 10 to 12) run about half-

* If p is constant, then
$S = (\alpha + \beta p) + l_1 (\gamma + \delta p) = A + B l_1$ (as above).
If the rib spacing l_1 is constant, then
$S = (\alpha + \gamma l_1) + p\, (\beta + \delta l_1) = S_0 + \zeta p$ (as above)

way between the more widely separated curves for small values of ρ_2 (Figs. 8, 9 and 16). For $\rho_2 = \infty$, $S_1 = S_2 = S$ becomes a mean value between the two curves for S_1 and S_2. It is of little use to give am equation for this, as wings are very seldom uniformly curved. It is sufficient to establish the fact that, with the usual under-side camber of wings, the two principal tensions are almost the same. With the sometimes rather highly cambered upper surface of the wings, on the contrary, the tensions in the separate curves must be estimated (See below).

5. The additional deflection f' of the fabric, as a function of the load p and the rib-spacing l_1, is a hyperbola given by

$$f' + f_{1_0} = \frac{p\, l_1^{\,2}}{Mp + N l_1 + Qp l_1} \qquad (7)$$

which expresses the effect of wing camber in terms of the quantities M, N and Q (compare equations 9 & 11, below).

Table IV.

Fabric B, previously stretched.
$\rho = 4.0$ m (13.123 ft)

l_1 m	0.28	0.40	0.28	0.40	0.28	0.40
l_1 ft	.919	1.312	.919	1.312	.919	1.312
Deflection	$f_{1_c} + f'$ mm in.		$f_{2_c} + f'$ mm in.		$\frac{\varphi_x - \varphi}{\varphi}$ 100 mm in.	
p = 0 kg/m²	-3.60	-5.75	70.1	67.9	-4.9	-7.8
0 lb/ft²	-.142	-.226	2.760	2.673	-.193	-.307
55 kg/m²	4.85 (6.90)	9.55 (14.40)	78.5 (80.6)	83.2 (88.1)	6.6 (9.4)	12.9 (19.6)
11.265 lb/ft²	.191 (.272)	.376 (.567)	3.090 (3.173)	3.276 (3.468)	.260 (.370)	.508 (.772)
110 kg/m²	9.60 (10.00)	18.60 (19.25)	83.3 (83.7)	92.3 (92.9)	13.0 (13.6)	25.2 (26.1)
22.530 lb/ft²	.378 (.394)	.732 (.758)	.328 (.330)	3.634 (3.657)	.512 (.535)	.992 (1.028)
165 kg/m²	11.95 (12.95)	21.20 (25.10)	85.6 (86.6)	94.8 (98.7)	16.2 (17.6)	28.7 (34.0)
33.795 lb/ft²	.470 (.510)	.835 (.988)	3.370 (3.409)	3.732 (3.886)	.638 (.693)	1.130 (1.339)
275 kg/m²	15.20 (17.80)	26.90 (30.30)	88.9 (91.5)	100.1 (104.0)	20.6 (24.2)	36.4 (41.0)
56.325 lb/ft²	.598 (.701)	1.059 (1.193)	3.500 (3.602)	3.940 (4.094)	.811 (.953)	1.433 (1.614)

Table V.

Fabric B, previously stretched.
$\rho_2 = 8.0$ m (26.247 ft)

l_1	m	0.23	0.5	0.23	0.5	0.23	0.5
	ft	.755	1.640	.755	1.640	.755	1.640
Deflection		$f_{1_c} + f'$ mm in.		$f_{2_c} + f'$ mm in.		$\frac{\varphi_x - \varphi}{\varphi} 100$ mm in.	
p =	0 kg/m²	-1.2	-4.8	33.5	29.9	-3.5	-13.8
	0 lb/ft²	-.047	-.190	1.319	1.177	-.138	-.543
	55 kg/m²	3.9 (7.3)	20.95 (21.2)	38.6 (41.95)	55.7 (55.9)	11.2 (20.9)	60.4 (61.1)
	11.265 lb/ft²	.154 (.287)	.825 (.835)	1.520 (1.652)	2.193 (2.201)	.441 (.823)	2.378 (2.405)
	110 kg/m²	8.8 (9.4)	27.6 (29.0)	43.4 (44.1)	62.3 (63.7)	25.2 (27.2)	79.6 (83.6)
	22.530 lb/ft²	.346 (.370)	1.087 (1.142)	1.709 (1.736)	2.453 (2.508)	.992 (1.071)	3.134 (3.291)
	165 kg/m²	9.1 (11.5)	32.3 (32.7)	43.8 (46.2)	67.0 (67.3)	26.2 (33.2)	93.0 (94.0)
	33.795 lb/ft²	.358 (.453)	1.272 (1.287)	1.724 (1.819)	2.638 (2.650)	1.031 (1.307)	3.661 (3.701)
	275 kg/m²	12.8	37.6	47.5	72.0	36.9	108.0
	56.325 lb/ft²	.504	1.480	1.870	2.835	1.453	4.252

Table VI.

ρ_2 = 4 m (13.123 ft)

		S_1	S_2	ϵ_1	ϵ_2
l_1 m		0.32			
l_1 ft		1.050			
		kg/m* lb/in*		Per cent	
p = 50 10.241	kg/m^2 lb/ft^2	42.0 2.352	55.0 3.080	0.31 "	0.18 "
100 20.482	kg/m^2 lb/ft^2	73.0 4.088	86.0 4.816	0.48 "	0.23 "
150 30.723	kg/m^2 lb/ft^2	103.0 5.768	110.0 6.160	0.60 "	0.27 "
l_1 m		0.40			
l_1 ft		1.312			
		kg/m* lb/in*		Per cent	
p = 50 10.241	kg/m^2 lb/ft^2	48.0 2.688	65.0 3.640	0.32 "	0.23 "
100 20.482	kg/m^2 lb/ft^2	86.0 4.816	105.0 5.880	0.47 "	0.30 "
150 30.723	kg/m^2 lb/ft^2	120.0 6.720	129.5 7.252	0.63 "	0.36 "
l_1 m		0.50			
l_1 ft		1.640			
		kg/m* lb/in*		Per cent	
p = 50 10.241	kg/m^2 lb/ft^2	55.0 3.080	80.0 4.480	0.31 "	0.26 "
100 20.482	kg/m^2 lb/ft^2	99.0 5.544	120.0 6.720	0.51 "	0.35 "
150 30.723	kg/m^2 lb/ft^2	137.5 7.700	147.0 8.232	0.68 "	0.37 "

*) Unit of width.

Table VII.

ρ_2 = 8.0 m (26.247 ft)

l_1	S_1	S_2	ϵ_1	ϵ_2
m	0.32			
ft	1.050			
	S_1 kg/m* lb/in*	S_2 kg/m* lb/in*	ϵ_1 Per cent	ϵ_2 Per cent
p = 50 kg/m^2 10.241 lb/ft^2	46.8 2.621	50.0 2.800	0.37 "	0.11 "
100 kg/m^2 20.482 lb/ft^2	79.0 4.424	80.0 4.480	0.56 "	0.16 "
150 kg/m^2 30.723 lb/ft^2	108.0 6.048	104.0 5.824	0.68 "	0.17 "
m	0.40			
ft	1.312			
	S_1 kg/m* lb/in*	S_2 kg/m* lb/in*	ϵ_1 Per cent	ϵ_2 Per cent
p = 50 kg/m^2 10.241 lb/ft^2	54.0 3.024	60.0 3.360	0.4 "	0.16 "
100 kg/m^2 20.482 lb/ft^2	92.0 5.152	95.0 5.320	0.6 "	0.2 "
150 kg/m^2 30.723 lb/ft^2	127.0 7.112	122.0 6.832	0.75 "	0.22 "
m	0.50			
ft	1.640			
	S_1 kg/m* lb/in*	S_2 kg/m* lb/in*	ϵ_1 Per cent	ϵ_2 Per cent
p = 50 kg/m^2 10.241 lb/ft^2	63.5 3.556	76.0 4.256	0.42 "	0.21 "
100 kg/m^2 20.482 lb/ft^2	111.0 6.216	118.0 6.608	0.62 "	0.27 "
150 kg/m^2 30.723 lb/ft^2	151.0 8.456	150.0 8.400	0.79 "	0.33 "

* Unit of width.

Remarks on Previous Coverings.

It follows from the results of the stress calculations, that the strength of the fabric is amply sufficient. If the tensile strength of the fabric usually employed is taken from Tables I and II previously communicated (Technische Berichte, Volume III, No.2, p.58, then the tensions in Tables VI and VII correspond to the following factors of safety of the covering fabric.

Table VIII.

Factors of safety.

ρ_1		m	4.0			
		ft	1.312			
l_1		m	0.32	0.50	0.32	0.50
		ft	1.050	1.640	1.050	1.640
			Warp		Filling	
p =	50	kg/m^2	19.2	13.2	29.0	22.2
	10.241	lb/ft^2	"	"	"	"
	100	kg/m^2	12.5	8.8	16.7	12.3
	20.482	lb/ft^2	"	"	"	"
	150 150	kg/m^2	9.6	7.2	11.8	8.9
	30.723	lb/ft^2	"	"	"	"
ρ_2		m	8.0			
		ft	2.625			
l_1		m	0.32	0.50	0.32	0.50
		ft	1.050	1.640	1.050	1.640
			Warp		Filling	
p =	50	kg/m^2	21.0	14.0	26.0	19.2
	10.241	lb/ft^2	"	"	"	"
	100	kg/m^2	13.2	9.0	15.5	11.0
	20.482	lb/ft^2	"	"	"	"
	150	kg/m^2	10.2	7.0	11.3	8.1
	30.723	lb/ft^2	"	"	"	"

According to this, with regard only to the strength of the fabric, the rib spacing might be greater than hitherto. In any case, it could be increased, without danger, up to l_1 = 50 cm (1.64 ft) and even more, so long as considerations of deformation do not forbid. Under otherwise like conditions, the tearing strength of doped fabrics can be decreased to about 1000 kg/m (56 lb/in) in warp and woof, if it is possible to keep the distortions small at the same time. Tests with semi-linen fabrics are contemplated.

Distortions under load seem rather large. At a load of only 50 kg/m² (10.24 lb/ft²) in the most favorable case (ρ_2 = 4 m (13.123 ft) l_1 = 0.32 m (1.05 ft)) additional deflection of $f' + f_{1_c}$ = 10 mm (.0328 ft) have been observed, with corresponding alterations of the camber ratio from 0.048 up to 0.055. This, however, lowers the aerodynamical qualities of the wing (L/D, gliding angle and center of pressure, with its effect on stability).

The extensibility of the fabric depends chiefly on the dope used, since it is difficult to maintain high initial tensions while attaching undoped fabric.

The outermost ribs of the supporting framework are stressed by the full tension S_1; the others only by the differences of S_2 between panels. On the other hand, the wire or strip at the rear edge of the wing receives the full stress due to the tension S_2, from both the upper and the lower surfaces. Their loading and distortion increase with the rib spacing. If the latter is increased, in order to lighten the wing, the rear edge must be adequately strengthened (calculation of bending moments under uniform loading of S_2 kg/m, with special attention to buckling.

The distortion of the framework, as a whole, may seriously affect the tensions in the fabric.

Approximate Calculation.

The following equations may serve for a rapid estimation of the stresses to be expected.

$$S_1 \sim S_2 = S \qquad (1)$$

$$\left.\begin{aligned} \epsilon_1 &= S\ (\beta_1 - c_1) \\ \epsilon_2 &= S\ (\beta_2 - c_2) \end{aligned}\right\} \qquad (2)$$

Also the general equation of the C-curves

$$S_1 \sqrt{\epsilon_2} = \frac{S\, l_1}{2\sqrt{6}}\left(1 - \frac{S_2}{p\rho_2}\right) \qquad (3)$$

or, with

$$S_1 = S_2 = S$$

$$S^{3/2}\sqrt{24\ (\beta_1 - c_1)} = \left(1 - \frac{S}{p\,\rho_2}\right) p\, l_1 \qquad (4)$$

from which, preferably graphic with known values of p and ρ_2, the tension S can be calculated.

Thus, in the former numerical example, with

$p = 150\ \text{kg/m}^2$ ($30.723\ \text{lb/ft}^2$), $l_1 = 0.32$ m (1.05 ft) and fabric constants $\beta = \frac{120}{10^6}$, $c_1 = \frac{30}{10^6}$,

we get

$$0.00097\ S^{3/2} = 1 - \frac{S}{150\ \rho_2}$$

The left-hand side of this equation gives a curve, the right hand side a set of diverging lines (ρ_2 = 2 (6.56), 4 (13.12), 6 (19.68) and 8 m (26.24 ft) whose intersections with the curve give the abscissas S_1 = 82 (4.59), 90 (5.04), 95 (5.32), 97 kg/m (5.43 lb/in). From this, it is easy to see that the tension S decreases somewhat with a decreasing radius of curvature of the wing. Hence, with greater wing curvature, a more accurate calculation of S_1 and S_2 can be made. ρ_2 is first assumed to be ∞ and an average value is taken for S, whereby S_2 can be assumed to be just as much larger than S as S_1 is smaller than S, to a sufficient degree of approximation. In the above example, if S = 102 kg/m (5.71 lb/in) with ρ_2 = 2 m (6.56 ft), then S_1 = 82 kg/m (4.59 lb/in) and, accordingly, S_2 = 122 kg/m (6.83 lb/in).

This simplified method can also be used for the estimation of the markedly different stresses S_1 and S_2 on the more highly cambered parts of the upper surface of the wing.*

* It is usually convenient to use the known radius wing curvature, deflection f_2 (or $f_2 + f'$), instead of the unknown

$$\rho_2 = \frac{l_2^2}{8f_2} \quad \text{or} \quad = \frac{l_2^2}{8(f_2 + f')}$$

then

$$S^{3/2}\sqrt{24(\beta_1 - c_1)} = \left(1 - \frac{8(f_2 + f')S}{p\,l_2}\right) p\,l_1$$

$$= p\,l_1 - \frac{8(f_2 + f')l_1}{l_2^2} S.$$

Additional deflection f' resulting from Loading and Rib spacing.

Taking into consideration the negative deflection f_{1_0}, of the unloaded surface, we have

$$S_1(f_1 + f') = \frac{p\,l_1^2}{8}\left(1 - \frac{S_2}{p\,\rho_2}\right). \tag{5}$$

and

$$\rho_2 = \frac{l_2}{8(f_{2_0} + f')} \tag{6}$$

where the fabric camber parallel to the ribs need not be the same as the rib camber. Whence it follows that

$$f' = \frac{p\,l_1^2}{8S_1 + 8S_2\,\frac{l_1^2}{l_2^2}} - \frac{\frac{S_2}{S_1}\,\frac{l_1^2}{l_2^2}\,f_{2c}}{1 + \frac{S_2}{S_1}\,\frac{l_1^2}{l_2^2}} - \frac{f_{1_0}}{1 + \frac{S_2}{S_1}\,\frac{l_1^2}{l_2^2}} \tag{7}$$

If we put $S_2 \infty S_1 = \beta p + \gamma l_1 + \delta p l_1$, then

$$\frac{p\,l_1^3}{ap + b\,l_1 + cp\,l_1 + dp\,\frac{l_1^2}{l_2^2} + \frac{l_1^3}{l_2^2} + gp\,\frac{l_1^3}{l_2^2}} - l_1^2\,\frac{f_{2_0}}{l_1^2 + l_2^2} - f_{1_c}\,\frac{l_2^2}{l_1^2 + l_2^2} \tag{8}$$

in which a, b .... g are established coefficients.

If p = constant, then

$$f' = \frac{l_1^2}{A + Bl_1 + Cl_1^2 + Dl_1^3} - l_1^2\,\frac{f_{2_0}}{l_2^2 + l_1^2} - f_{1_0}\,\frac{l_2^2}{l_1^2 + l_2^2} \tag{8a}$$

the expression for the relation between the deflection and the rib spacing.

Since l_1 is usually small compared with l_2, the terms C, D, l_1^2 and l_2^2 can be neglected and we have

$$f' + f_{1_c} \sim \frac{l_1^2}{A + Bl_1} - l_1^2 \frac{f_c}{l_2^2} \sim \frac{l_1^2}{A + Bl_2} \tag{9}$$

the equation of a hyperbola, for which an approximation is given in Fig. 16.

For l_1 = constant,

$$f' = \frac{p}{\frac{ap}{l_1^2} + \frac{b}{l_1} + \frac{cp}{l_1} + \frac{dp}{l_2^2} + \frac{el_1}{l_2^2} + \frac{gl_1}{l_2^2}p} - \frac{f_{2_c}\ l_1^2}{l_1^2 + l_2^2} - \frac{f_{1_c}\ l_2^2}{l_1^2 + l_2^2} \tag{10}$$

$$f' + f_{r_c} \sim \frac{p}{E + F_p} - \frac{l_1^2\ f_{2_c}}{l_2^2} \tag{11}$$

$$\rho_2 = \frac{l_2^2}{8f_2} \quad \text{or} \quad = \frac{l_2^2}{8(f_2 + f')}$$

Then

$$S^{3/2}\sqrt{24(\beta_1 - c_1)} = \left(1 - \frac{8(f_2 + f')S}{p\,l_2}\right)p\,l_1$$

$$= p\,l_1 - \frac{8(f_2 + f')l_1}{l_2^2}S$$

This also gives hyperbolas (Figs. 14 and 15). If $p - 0$, then $f' = 0$ and it follows that

$$f_{1_0}\,l_2^2 + f_{2_0}\,l_1^2 = 0 \tag{12}$$

or, more exactly

$$S_{2_c}\ l_1^2\ f_{2_c} + S_{1_c}\ l_2^2\ f_{1_0} = 0 \tag{13}$$

as the relation between the initial cambers.

Non-uniform Loading.

The uniform loading of supporting surfaces, which is most convenient for experiments, scarcely comes into question in actual flight. According to the well-known representation of air forces by Eiffel, Baumann and others, the load diagram is more in the form of a triangle, with maximums well forward.

For steep dives, Reissner has established the loading on the basis of Foppl's experiments (Sonderheft des Jahrb. der W.G.L., 1915).

Owing to the constantly varying load, it is of little use to test the fabric under variable loading and hunt for differences, which, in practice, can only be of secondary importance. In principle, it must suffice to investigate a simple case of non-uniform loading, and compare the result with that obtained under uniform load. A triangular load distribution was selected for this purpose, the heaping of the sand being deepest over the forward spar in one test and behind the rear spar in the other test, decreasing to no load toward the middle of the wing. The remaining portion of the wing is quite unloaded. Results are given in Table IX, and Figs. 17-19.

Diminution of Distortions.

The distortions in direction 1, leads to the formation of "pockets", while distortions in direction 2 alter the aerodynamically determined wing section, by increasing the camber ratio. *

* The camber ratio φ corresponds to 1% of the "camber" Ψ of the Göttingen wing tests.

$(\varphi = \frac{\text{camber}}{\text{chord}}$ (Compare Tables I to V).

The alteration of the camber ratio, $\frac{\varphi_x - \varphi}{\varphi}$ is considerable along the chord and (as may be seen from Figs. 20 and 21) depends on the camber, as well as on the rib spacing. The alteration is specially great in wings of very small camber. In flight, the actual wing sections do not agree with those calculated, but, with steeper camber, the drag increases faster than the lift and, since the flying speed is reduced, it is necessary to reduce the angle of attack. In this case, increased drag is often set up by the unfavorable attitude of the fuselage.

In seeking to improve the conditions imposed, in particular by reducing the deformation, there comes into question the increase of the initial tension in the fabric and the application of a strongly contracting dope; further, the closer spacing of the ribs, the partial covering with veneer at places highly loaded and exposed to distortion (the forward third) and different methods of attaching the fabric.

Increased initial tension in the fabric, in any case, is bound up with greater stresses, though this is permissible, according to experiments thus far tried (Table VIII). The permissibility of increasing the tension of the fabric seems doubtful for the ribs and especially for the stiffening piece at the trailing edge of the wing. To this is added the impossibility of effecting the increased initial stretching of the plain fabric by hand and the difficulty of correcting it afterwards.

In this case, tension-measuring instruments should be used and stress should be laid on the measurement and continuous observation of the tensions.

Cellon dopes with a strong contracting effect are available, with which it is intended to undertake experiments.

The diminution of the rib spacing is, in fact, the most effective means of eliminating distortion of the wing. In any case, the deflection does not decrease in proportion to the diminished spacing (See Fig. 16). However, with narrower spacing, the initial stretching may be safely increased and a marked improvement made. The increase in weight is a disadvantage and it must, therefore, always be considered whether it is more important to maintain the shape of the wing (higher speed) or reduce its weight (better climbing ability). Generally, short formers inserted in the forward half of the wing, between the ribs, will give good service and not make the wing too heavy.

Experiments with other arrangements and treatments of the fabric have been started (See below). The improvements attained were indeed small, but initially stretched fabric seems, thus far, to offer advantages which justify further experiments. Finally, there is the possibility of lessening distortion by restricting the elongation of the threads, even at the cost of their strength. For this purpose, experiments with varying thicknesses of threads, or with stiffer even if weaker, threads would have to be conducted.

Experiments with Different Dispositions of the Fabric, and with Initially Stretched Fabric.

In previous experiments, the fabric, as is usually done, was stretched on the frame with the filling at right angles to the ribs. In this case, the elongation in direction 1 (filling) was always greater than in direction 2 (warp). In most of the fabrics used, however, (as follows from extension tests and from the N.C.), the elongation along the filling with otherwise similar conditions, is usually greater than along the warp. (The difference in the behavior of different fabrics is brought out elsewhere.)

It would be well, therefore, to test a covering in which the filling lay parallel and the warp at right angles to the ribs. In this case, the disadvantage is presented that the width of the fabric is smaller than the chord of the wing, so that a seam parallel to the spar is the result. It would, however, be possible, if this method offered special advantages, to adapt the width of the loom to the length of the wing chord.

Table IX.

Non-uniform loading.
ϱ_2 = 4.0 m (13.123 ft) l_1 = 0.4 m (1.312 ft).
Fabric B.

Load	Doped twice.			Doped, painted and varnished.		
	Deflections at points on Figs. 17 to 19.					
	2	5	8	2	5	8
	mm in	mm in	mm in	mm in	mm in	mm in
0 . . . . 0	44.8 1.764	68.4 2.693	66.6 2.622	41.3 1.659	65.0 2.560	63.0 2.480
100 kg rear 220 lb "	37.5 1.476	64.0 2.520	81.4 3.205	42.5 1.673	70.0 2.756	83.7 3.295
100 kg front 220 lb "	55.0 2.165	71.0 2.795	83.0 3.268			

Experiments have, so far, been conducted only on a test surface (See Table V). The distortions are, in part, somewhat less than with an otherwise similar arrangement (Fig. 22), but the results do not yet suffice for final conclusions. Above all, the behavior of the material may have been affected by slight differences in treatment. Accordingly, further experiments are contemplated. With abnormally large bending of the spars (weak construction), as will be pointed out later, a more serious effect would have been noted. In any case, the method of laying fabric with its filling, where tendency to elongate is greater, parallel to the spars, is recommended.

If the fabric is repeatedly subjected to the same load, after being unloaded each time, only a small increase in the deflection appears. In one experiment, the fabric after attachment, was given only one coat of "Cellon" and then subjected to a uniform sand load of 300 kg/m^2 (61.445 lb/ft^2) for a duration of 36 hours. After unloading, the fabric was removed, and again attached to the framework, in process of which it was now possible to stretch it by hand about 6% more in each direction. The fabric was then further heavily doped. This surface was subjected to the same tests as the others, in particular the same as a very similar one, which was twice doped, but not subjected to a preliminary stretching.

The results (Table IV and Fig. 23) show that the previously stretched fabric had a somewhat smaller deflection than the fabric used for comparison. The comparatively rapid and complete recovery of the fabric after long-continued loading, is noteworthy. Similar experiments were undertaken on two rectangular frames (100 × 30 cm - 39.37 × 11.811 in.) covered with fabric. The difference, however, was very slight under small loads (60 kg/m^2, - 12.289 lb/ft^2), while the fabric not previously stretched gave even better results. This, however, can be explained by the fact that the previously loaded material was stretched unequally and insufficiently by hand, the dropped-ball test showing that the previously stretched fabric had less initial tension.

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Figs. 1,2 & 3

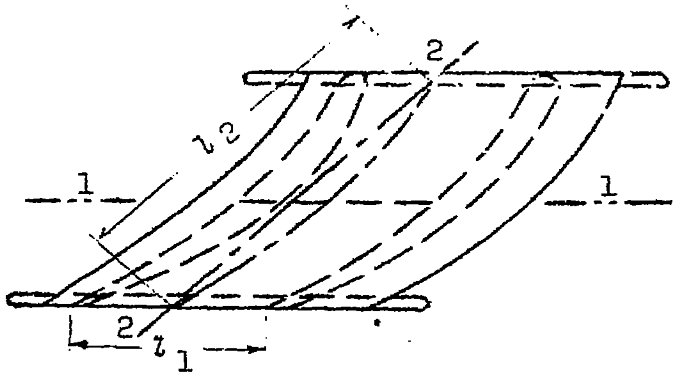


Fig. 1

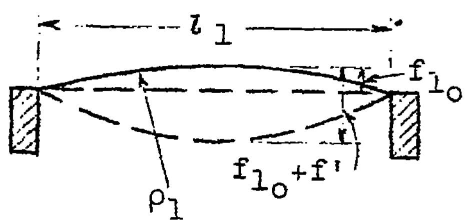


Fig. 2

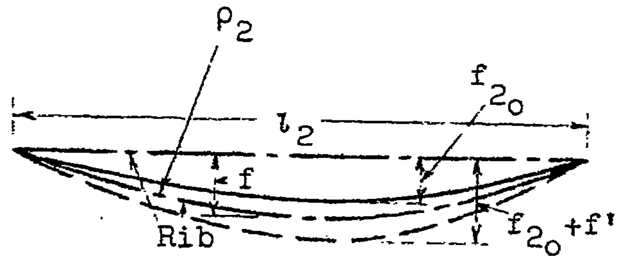
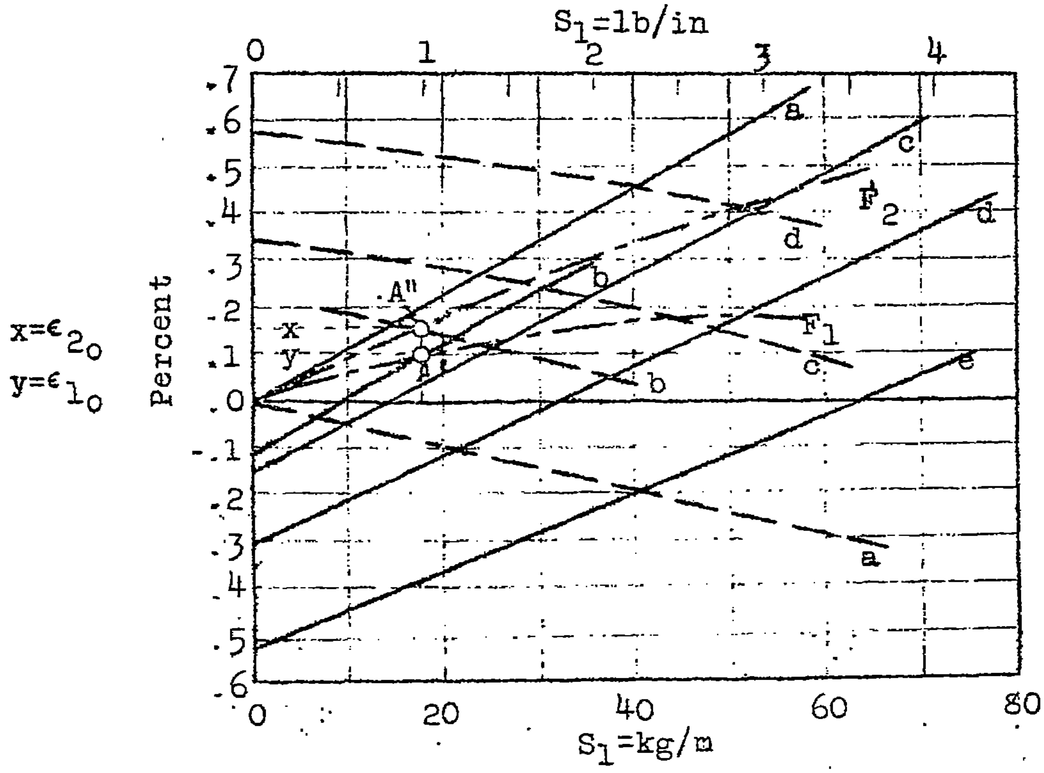


Fig. 3

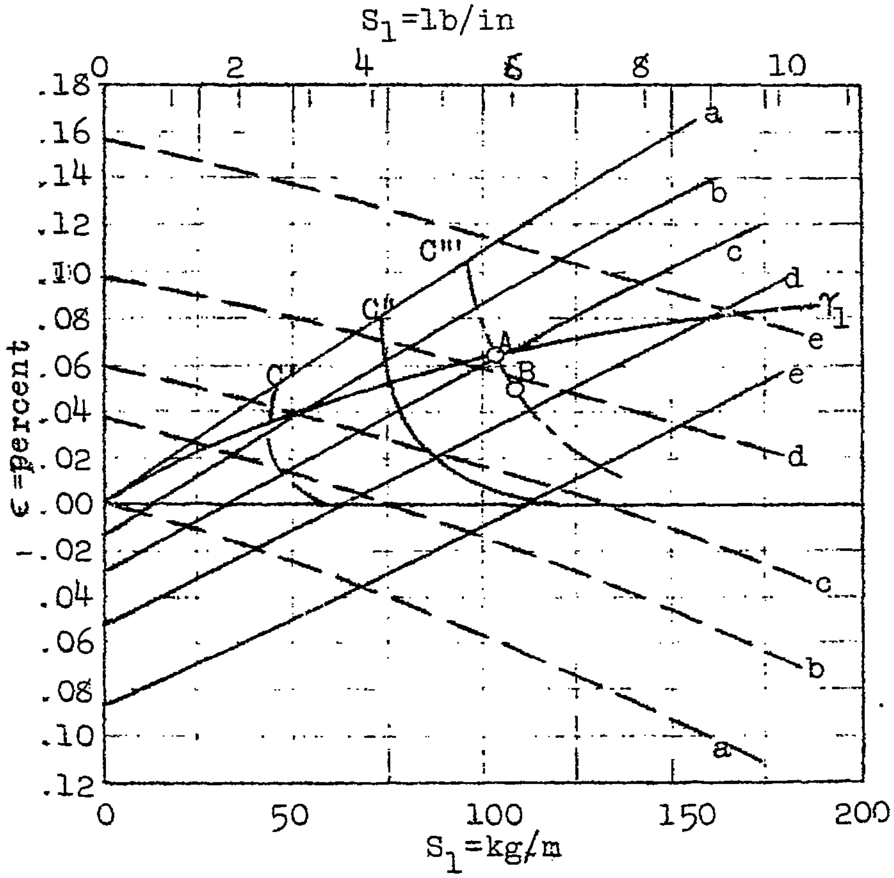
Fig. 4



a=S_2= 0 kg/m (0.000 lb/in)
b=S_2= 35 kg/m (1.960 lb/in)
c=S_2= 55 kg/m (3.080 lb/in)
d=S_2=100 kg/m (5.600 lb/in)
e=S_2=155 kg/m (8.670 lb/in)

Fig. 4

Fig. 5



a=S_2= 0 kg/m (00.000 lb/in)
b=S_2= 55 kg/m (3.080 lb/in)
c=S_2=100 kg/m (5.600 lb/in)
d=S_2=150 kg/m (8.400 lb/in)
e=S_2=267 kg/m (14.951 lb/in)

C' (l_1=0.32, p= 50)
C" (l_1=0.32, p=100)
C''' (l_1=0.32, p=150)

Fig. 5

Figs. 6 & 7

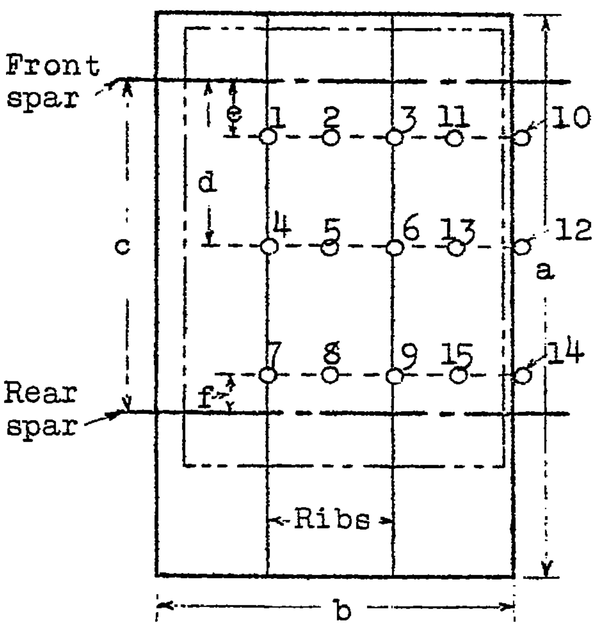


Fig. 6

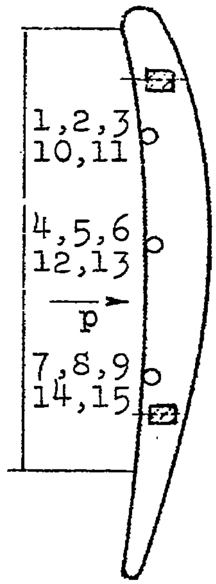
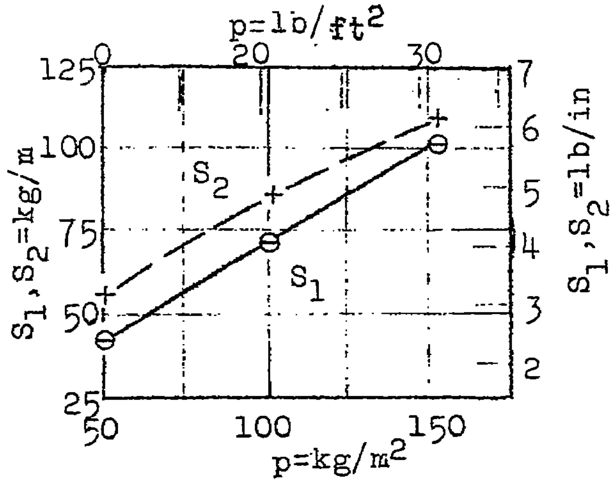


Fig. 7

a=1.53 m (5.020 ft)
b=0.95 m (3.117 ft)
c=0.90 m (2.953 ft)
d=0.45 m (1.476 ft)
e=0.15 m (0.492 ft)
f=0.10 m (0.328 ft)

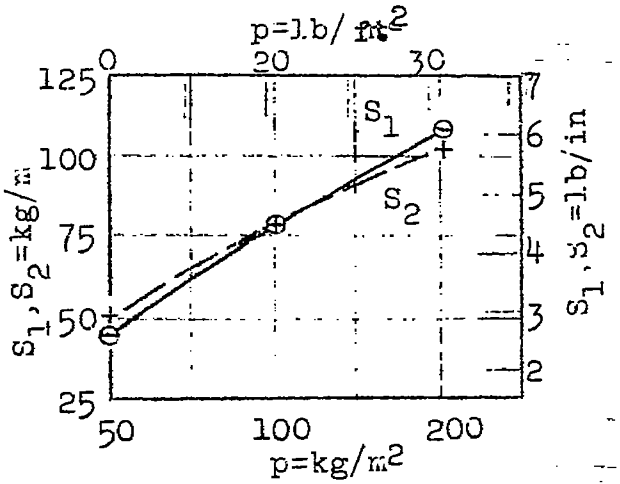
Framework for testing the effect of different settings of the ribs

Figs. 8,9,10 & 11



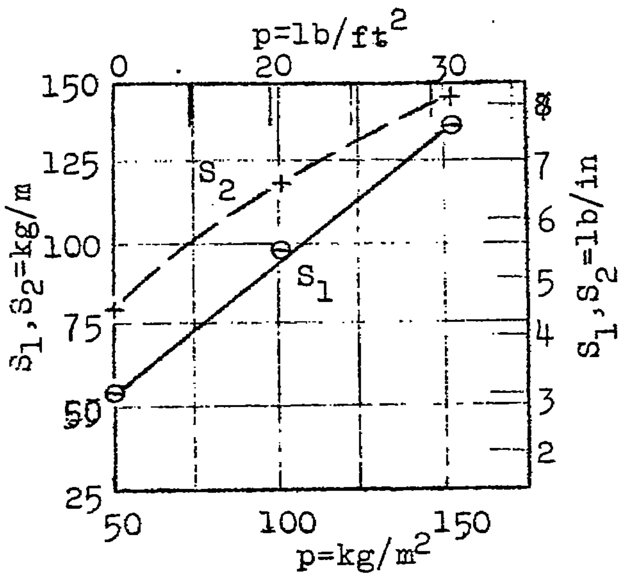
$S_2=\rho_2=4.0$ m (13.123 ft)
$S_1=l_1=0.32$m (1.050 ")

Fig. 8



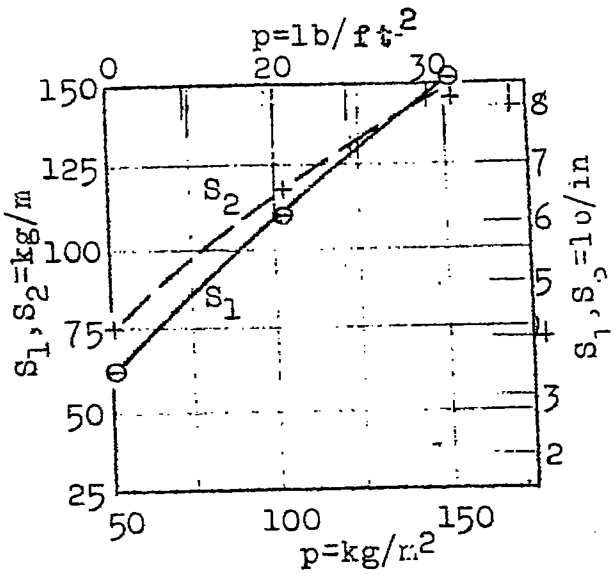
$S_2=\rho_2=8.0$ m (26.247 ft)
$S_1=l_1=0.32$m (1.050 ")

Fig. 10



$S_2=\rho_2=4.0$ m (13.123 ft)
$S_1=l_1=0.50$m (1.640 ")

Fig. 9



$S_2=\rho_2=4.0$ m (13.123 ft)
$S_1=l_1=0.50$m (1.640 ")

Fig. 11

Tensions S_1 and S_2 plotted against the load p for rib spacing l_1 and radii curvature ρ_2

Figs.12,13 & 16

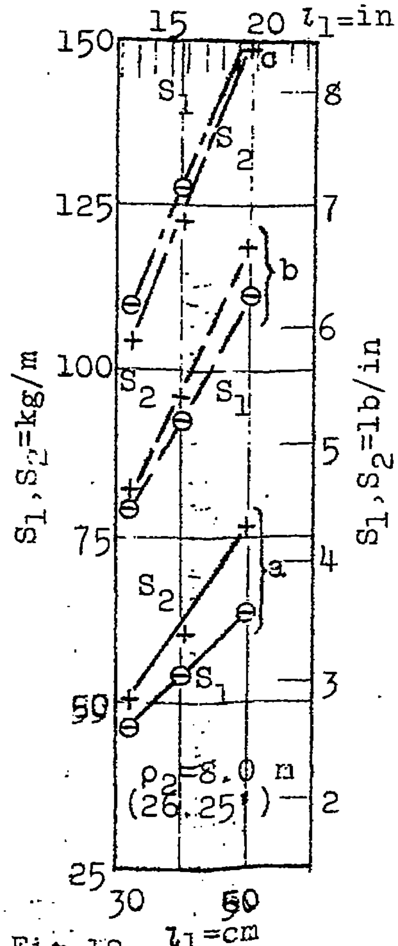


Fig.12

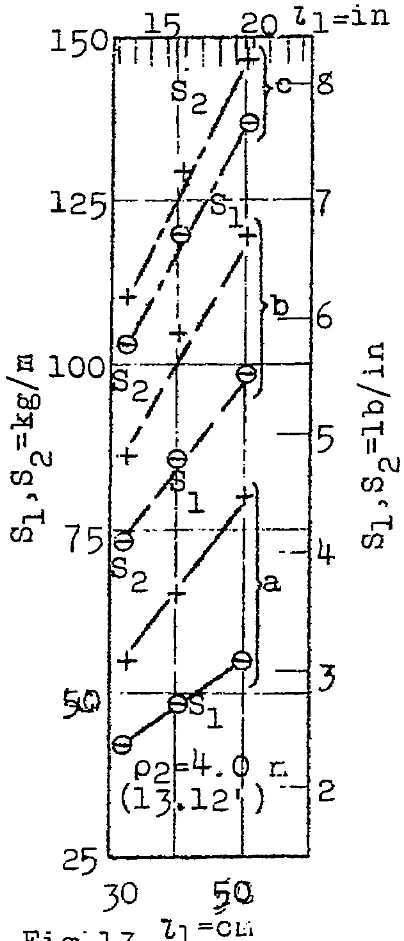


Fig.13

Figs.12 & 13. Tensions S_1 and S_2 plotted against the rib spacing l_1 at different loads p

a= 50 kg/m² p (10.241 lb/ft²)
b=100 kg/m² p (20.482 lb/ft²)
c=150 kg/m² p (30.723 lb/ft²)
d=265 kg/m² p (54.277 lb/ft²)
e=165 kg/m² p (33.795 lb/ft²)
f=110 kg/m² p (22.530 lb/ft²)
g= 55 kg/m² p (11.265 lb/ft²)

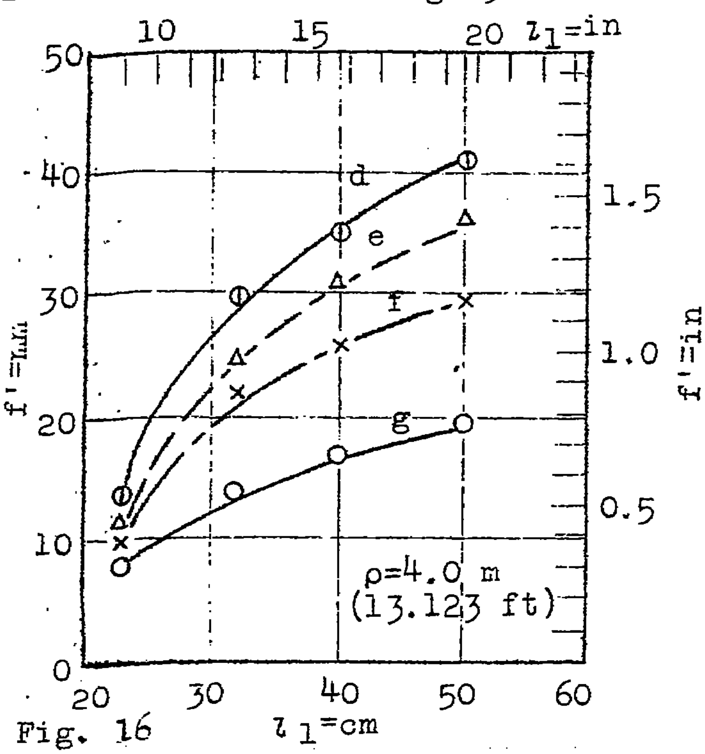


Fig. 16

Fig.16. Additional deflection f' with constant loading p

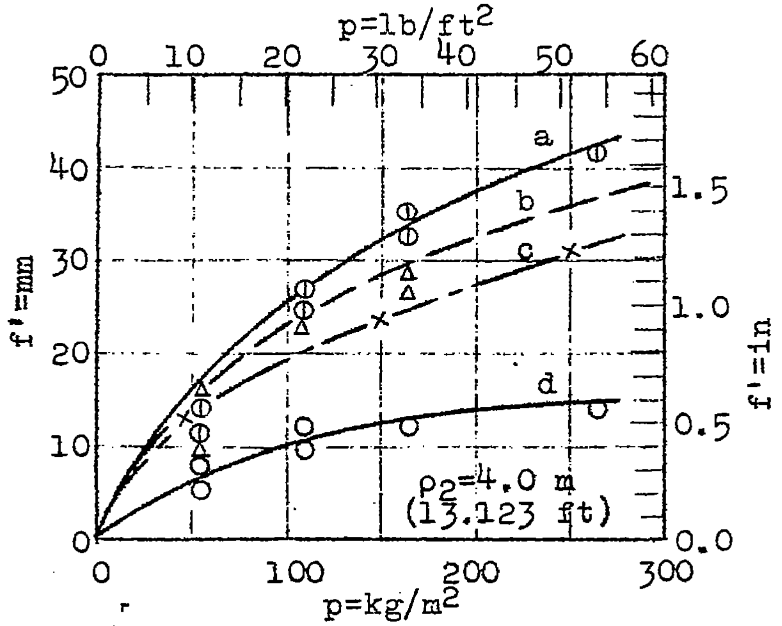


Fig. 14 Additional deflection f' with constant rib spacing l_1

$a=l_1=0.50$ m (1.640 ft) $c=l_1=0.32$ m (1.050 ft)
$b=l_1=0.40$ m (1.312 ft) $d=l_1=0.23$ m (0.755 ft)
$e=l_1=0.28$ m (0.919 ft)

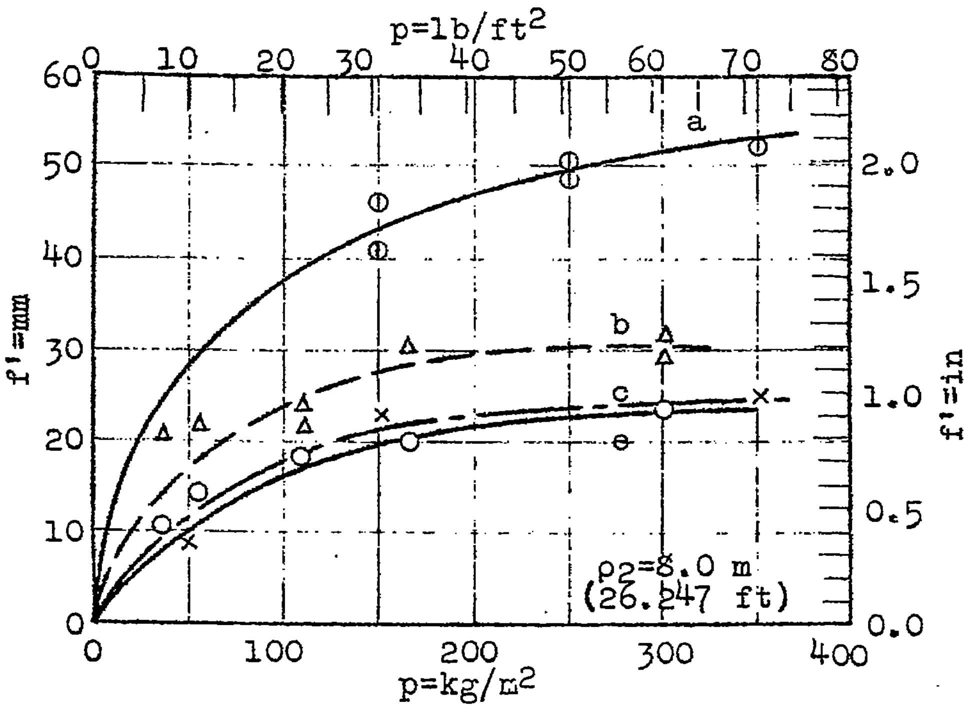


Fig. 15 Additional deflection f' with constant rib spacing l_1

Figs. 17, 18, & 19

a=1.53 m (5.020 ft) b=100 kg (220.46 lb)

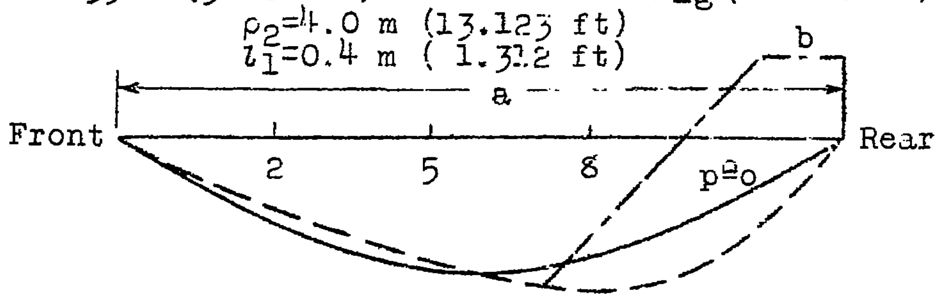


Fig. 17 Fabric B, twice doped with non-uniform loading

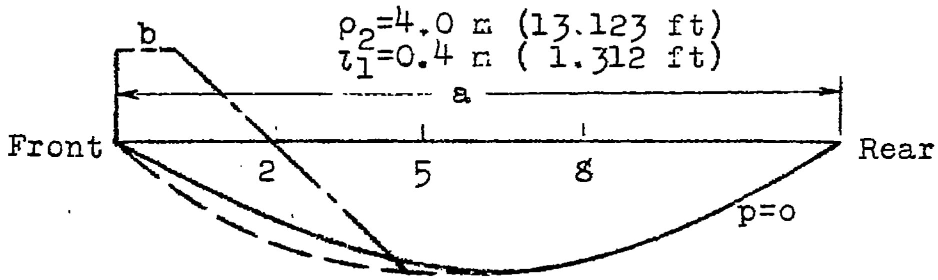


Fig. 18 Fabric B, twice doped with non-uniform loading

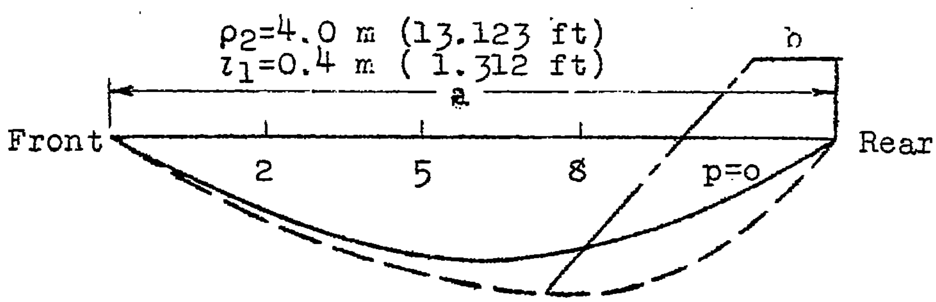
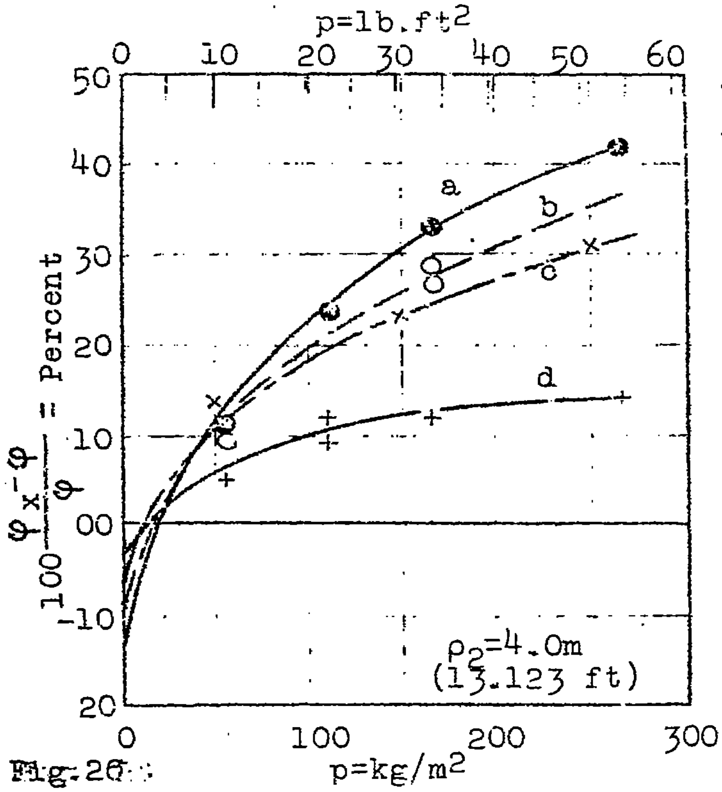


Fig. 19 Fabric B, doped, painted and varnished with non-uniform loading

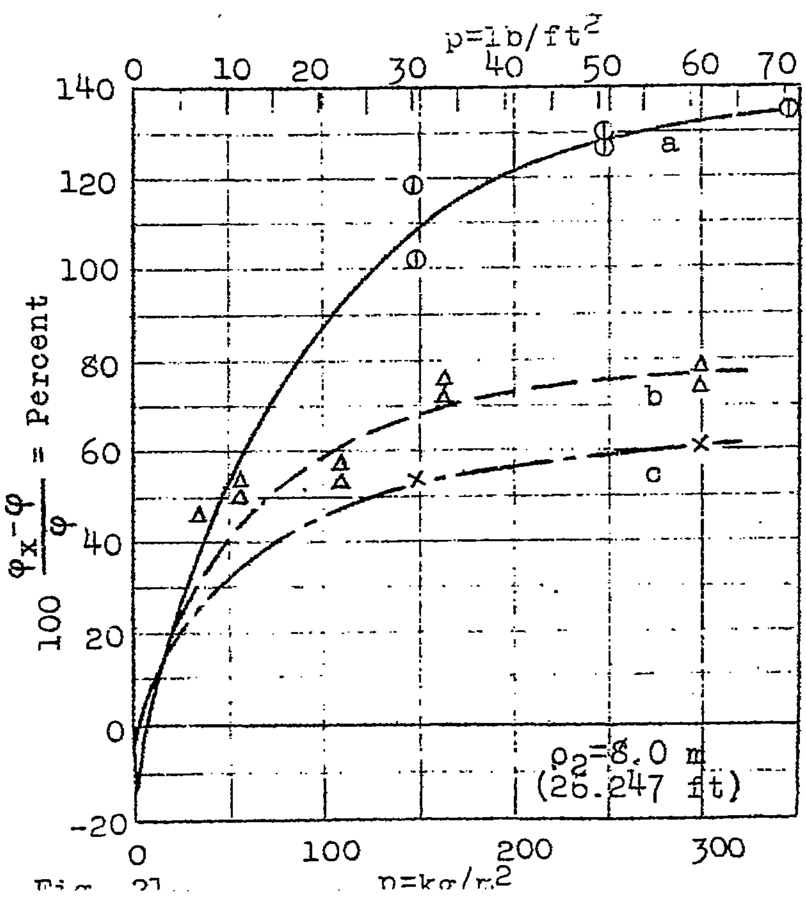
Figs. 20 & 21



a=l_1=0.50 m (1.640 ft)
b=l_1=0.40 m (1.312 ft)
c=l_1=0.32 m (1.050 ft)
d=l_1=0.23 m (0.755 ft)

Variation in camber ratio with the usual disposition of fabric-filling parallel to ribs

Fig. 20

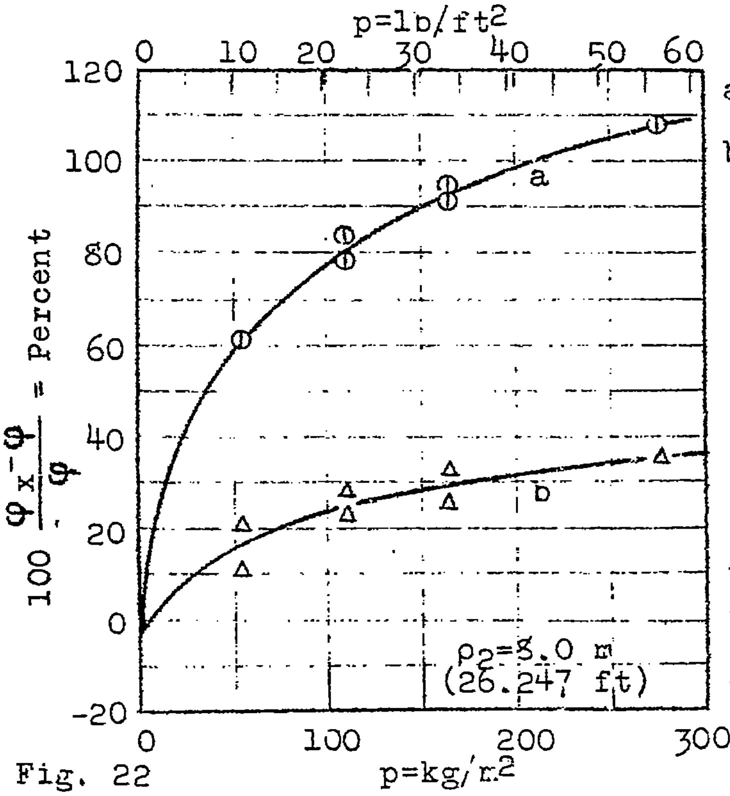


a=l_1=0.50 m (1.640 ft)
b=l_1=0.40 m (1.312 ft)
c=l_1=0.32 m (1.050 ft)

Variation in camber ratio with the usual disposition of fabric-filling parallel to ribs

Fig. 21

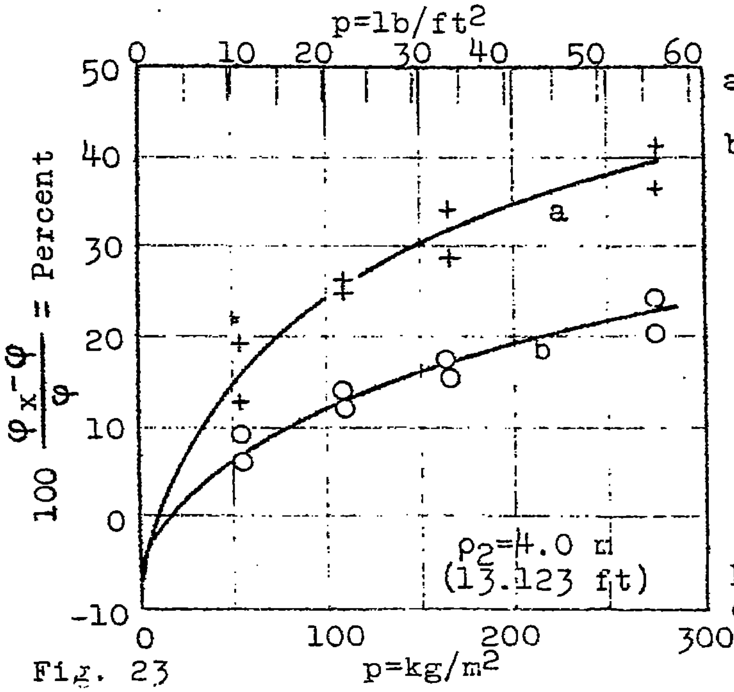
Figs. 22 & 23



$a = l_1 = 0.50$ m (1.640 ft)
$b = l_1 = 0.23$ m (0.755 ft)

Varations in the camber ratio with the filling at right angles to the ribs

Fig. 22



$a = l_1 = 0.40$ m (1.312 ft)
$b = l_1 = 0.28$ m (0.919 ft)

Previously stretched fabric

Fig. 23